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# THE FOREST FORMATIONS OF BOULDER COUNTY, COLORADO

ROBERT T. YOUNG

(WITH TWELVE FIGURES)

The present paper purposes to describe the forest formations of the eastern slope of the Rocky Mountains in Boulder County, Colorado. There has been a large amount of work done on the flora of Colorado from the systematic and distributional standpoint, the results of which are contained in RYDBERG'S *Flora of Colorado* (Bull. 100, Colorado Agricultural College Experiment Station, 1906). In the publications of the Forestry Bureau, U. S. Department of Agriculture, and the U. S. Geological Survey, there are a few papers treating of the economy (and incidentally the ecology) of the forests of the state; while a popular paper by RAMALEY ("Remarks on the distribution of plants in Colorado east of the divide") appeared in *Postelsia* for 1901, in which is given a considerable mass of data on the distribution and ecology of the plants of this region; but as yet there has been done no work of an exact character in the determination of the physical conditions under which the forests exist. For this reason I hope that the following discussion will prove of value.

The discussion will cover the following points: introduction, being a brief account of methods employed and a short description of the physical features of the region studied; composition of the forests with reference to the controlling and most common secondary species, and the relationship between them; physical character of the habitat with reference to water content of the soil, temperature of air and soil, humidity, light, pressure (altitude), slope, and exposure; past and present extent of the forests and their present movement, including deforestation and reforestation. The time spent in the investigations upon which this paper is based includes the summers of the years 1902 to 1905 inclusive. [1]

## Introduction

The methods which I have employed are given in detail in a recent work, *Research methods in ecology*, by DR. F. E. CLEMENTS, and are therefore treated here very briefly. They include the use of a Draper psychrograph and thermograph, a geotome, aneroid barometer, maximum, minimum, and ordinary thermometers, egg-beater psychrometers, and a simple photometer.

A set of the Draper instruments was established in Boulder, at an altitude of $1620^m$, and at timber-line on the east slope of the Continental Divide at an altitude of about $3420^m$. A set of records of these instruments was taken between June 21 and July 20, 1905. The instruments were set each week by comparison with a watch and with the humidity and temperature readings obtained from the egg-beater psychrometer and the thermometer. The thermograph records were found to agree within a few degrees with the temperature as given by the thermometer, but very little confidence can be placed in the psychrograph records as the reading recorded by this instrument seldom, if ever, tallied with the readings given by the hand psychrometer, and in fact the two psychrographs when running side by side did not agree with each other closer than seven per cent.

A set of maximum and minimum thermometers was placed at the mouth of a small cañon at an altitude of $1710^m$ and readings taken weekly from June 23 to July 31, 1905. From August 4 to September 4 these were stationed on a moraine in open pine timber at an altitude of $2550^m$. Another set was kept on the open plains three miles east of Boulder at $1590^m$ altitude from the middle of June to the end of September.[2]

With the geotome, two soil cores were obtained at each station, one of the first $11.25^{cm}$, and one from 11.25 to $22.5^{cm}$ in depth.[3] These readings are of course not entirely satisfactory in determining the soil water available for the trees, with their roots extending to a depth of many feet; but the deeper sample probably gives a fair basis for comparison of habitats in this respect. It is exceedingly difficult in any extended investigation to carry a geotome which will reach a depth of several feet. The soil samples obtained

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[1] See below.

[2] The thermographs and psychrographs were elevated about $1.2^m$ above the ground, the maximum and minimum thermometers $0.6^m$. They were all carefully housed so as to protect them from the sun and yet afford free access to the air.

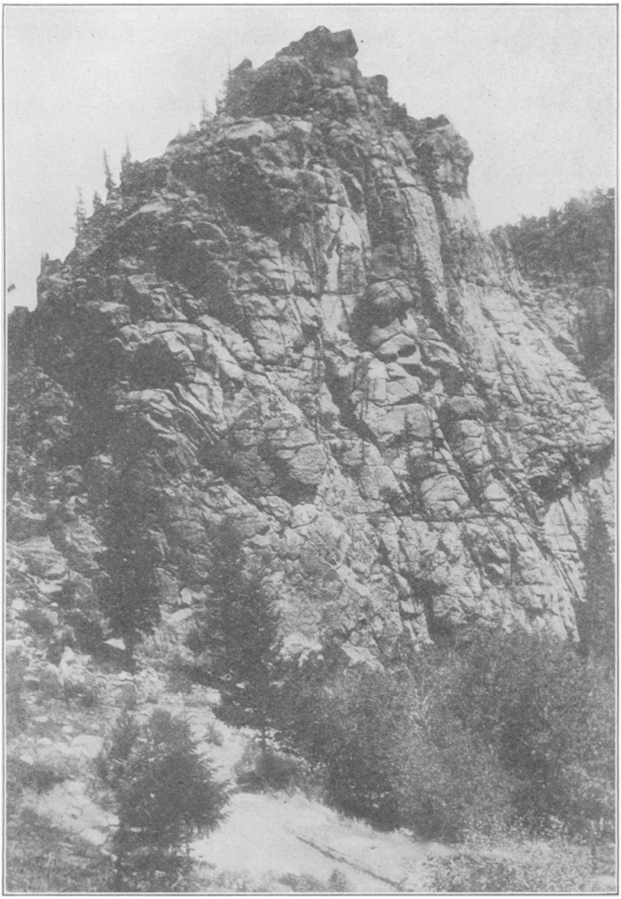

FIG. 1.—Castle Rock in Boulder Cañon, altitude 2250$^{m}$; in the foreground and to the right is seen the Populus angustifolia–Salix Nuttallii formation; scattered over the hills are Pseudotsugas and Piceas.

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[3] Exceptions to these depths will be noted below.

with the geotome were carried to the laboratory in Boulder in tightly closed tin cans and weighed as soon as possible after collection. They were then opened, the samples dried for three days at an average temperature of 24 to 29°C., after which they were weighed again. The difference between the two readings gave the weight of moisture contained in the soil, and this weight is expressed in per cent. of weight of the dried sample. In the case of soil samples which it was necessary to carry in the pocket for several days before weighing, an allowance of a few decigrams must be made, since there was a slight evaporation from the tins. This slight inaccuracy, however, is not sufficient to invalidate the general results.

At each station soil temperatures were taken on the surface of the ground and at depths of $11.25^{cm}$ and $22.5^{cm}$, respectively. The air temperature was taken at $7.5^{cm}$ and $9^{dm}$ above the ground; while humidity readings were also taken at $7.5^{cm}$ and $9^{dm}$ above the surface. Occasionally humidity and temperature readings at $1.8^{m}$ above the ground were taken.

The light readings in each formation were obtained with the photometer, and these were evaluated in terms of a standard series of ten readings of one to ten seconds respectively, taken at 12:30 P. M. on October 2 at $1620^{m}$ altitude in Boulder. A similar series was taken at noon on June 23, but unfortunately lost.

The aneroid barometer was used in obtaining the approximate altitudinal limits of the formations, and the altitudes so obtained were checked whenever possible by those obtained by the United States Geological Survey.

The observation stations were chosen at points as nearly typical as possible for each formation, and at most stations from three to many observations were taken during the summer of 1905.[4] Where the formations showed isolated societies within their limits, separate stations were selected for each of these.

Boulder County, Colorado, lies on either side of the fortieth parallel of north latitude. Its western boundary is the Continental Divide of the Rocky Mountains, while to the east it extends about $19^{km}$ from the base of the mountains. With the exception of the banks of streams on the plains, the forested area is confined to the mountains,

[4] Three observations were taken in 1907 as noted below.

which were originally pretty heavily timbered; but since the settlement of the region, the forests have been and still are disappearing. The topography of the mountains has been determined by vast elevation accompanied by extensive faulting, and followed by great erosion. The face of the country is exceedingly broken. High, rocky ridges alternate with deep cañons walled in by rocky precipices hundreds of feet in height, with an occasional granite dome isolated from the general mass. Such a dome is shown in *fig. 1*.

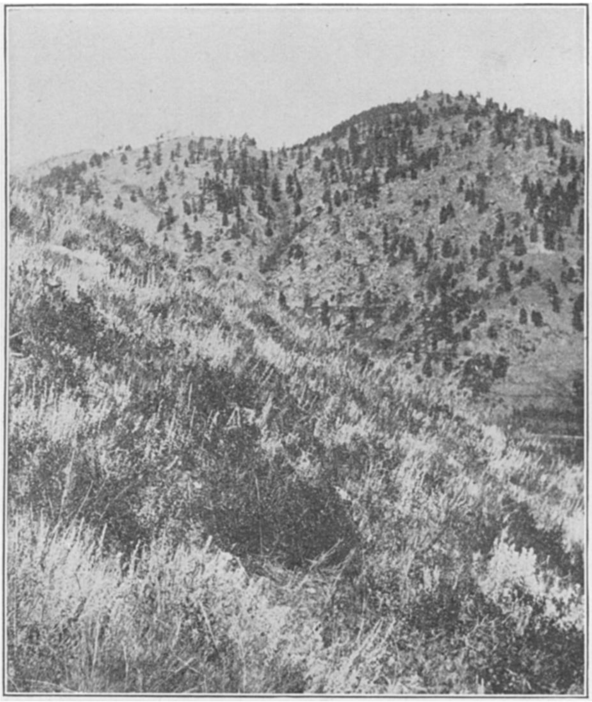

FIG. 2.—Foothills near Boulder; the altitude of the tops of the hills in the background is approximately 1950$^{m}$; in the foreground is seen the shrub-grass formation of the foothills, which in this view is dominated by a grass-sagebrush society; scattered over the hills in the background is *Pinus scopulorum*.

Passing from the plains westward toward the Continental Divide, we first encounter the foothill region of the main range (*fig. 2*). This is a region of broken ridges with steep slopes, cut at intervals of 1.5

to $7^{km}$ by larger and smaller cañons running from east to west, in which flow the streams. Extending north and south from these main cañons are numerous smaller cañons and gulches, so that the entire region is very irregularly furrowed in all directions. The foothill region is 6 to $8^{km}$ wide and at its summit reaches an altitude of about $2250^{m}$, although some of its individual peaks may reach a height of $2700^{m}$.

From the western end of the foothills to the base of the main range is a distance of about $16^{km}$. This is the plateau region, ascending gradually from $2250^{m}$ to $3000^{m}$ at the base of the range. While the surface of this region is much broken, it is less so than either the foothills to the east of it or the main range to the west, and its general contour is comparatively even. In its eastern part, however, where the streams lie far below the general level, are found the deepest and most rugged parts of the cañons. In its western portion are many beautiful little parks along the stream courses (*fig. 3*) which afford good crops of hay and excellent pasturage. Above $3000^{m}$ the country again becomes much broken, the steep and rocky slopes encountered above timber-line culminating at the crest of the range in vast chasms and inaccessible pinnacles of rock. Above $2400^{m}$ the mountains have been extensively glaciated. The ice sheet at the time of its greatest extent covered all but the highest ridges above $2700^{m}$, while tongues of ice in some places extended down to nearly $2400^{m}$. As evidence of this condition we have today the vast morainal deposits, the chains of little glacial lakes (*fig. 4*), and the existence of a small glacier on the eastern slope of the Arapahoe Peaks some $32^{km}$ west of Boulder. The highest summits in Boulder County are Mt. Audubon and the Arapahoe Peaks, with approximate altitudes of $4050^{m}$.

The principal streams are North, Middle, and South Boulder Creeks, Jim Creek, the North and South St. Vrains, and Left Hand Creek. All of these rise at the base of the range and flow eastward to join finally the North Platte River.

The climate of the region is semi-arid. At Boulder, situated directly at the base of the mountains, the average rainfall for nine years has been $42.7^{cm}$. In the higher mountains there is a much heavier annual rainfall than this, the difference between Boulder and the summit of the range being 25$^{cm}$ in 1904. The rainfall at the base of the mountains occurs mainly in April and May, but in the higher mountains it is distributed through spring and summer.

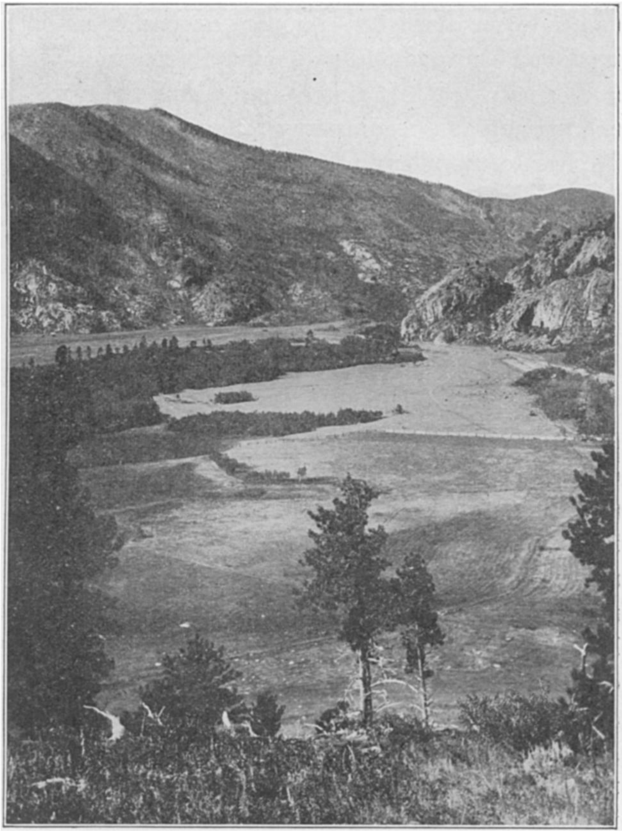

FIG. 3.—A mountain "park" on Boulder Creek, 35$^{km}$ west of Boulder; in the foreground are a few *Pinus Murrayana* and *Pinus scopulorum;* in the middle foreground is the upper extension of the Populus angustifolia–Salix Nuttallii formation intermingled with *Populus tremuloides* and Piceas; to the right is an aspen grove; on the mountain in the background is a burned area in Pseudotsuga and *Pinus Murrayana* timber, in the lower part of which are a few aspen groves.

The heavy snows of winter, packed in the ravines by the high winds, do not melt until late in summer and are the principal source of water for irrigation.

At the base of the mountains the temperature range is from 37°.7 to −34°.4, though neither of these figures is often reached by thermometers elevated a few feet above the surface of the ground.[5]

The following is the record of maximum and minimum temperatures obtained by me during the summer of 1905: At Boulder ($1620^{m}$) from June 21 to July 20 the maximum thermograph reading was 34°.4, the minimum 5°. At timber-line during the same period the maximum thermograph reading was 22°.2 and the minimum −3°.9. Three miles east of Boulder on the plains ($1590^{m}$) the maximum and minimum thermometers from June 13 to July 31 gave a maximum of 40°.3 and a minimum of 6°.1; from July 31 to August 31 a maximum of 41° and a minimum of 9°.7.[6] The instruments at the cañon mouth ($1710^{m}$) from June 13 to July 31 gave a maximum of 31° and a minimum of 7°.7, while those on a moraine ($2550^{m}$) from August 1 to August 29 gave a maximum of 30°.3 and a minimum of 4°.7. These results show an approximate difference in mean temperature of 11° between Boulder and timber-line, an approximate difference of 1° per $160^{m}$ altitude, the difference in the maxima being slightly greater and in the minima slightly less than this. It must of course be borne in mind in the study of these results that they are fragmentary, covering comparatively short periods.

As already remarked, comparatively little confidence can be placed in the psychrograph records. The curves traced by the two instruments are in no way conformable to each other, owing to the fact that the relative humidity is dependent on such local factors as sunlight and wind and hence is liable to sudden and considerable variations within limited areas. I have even known the temperature recorded by the wet-bulb thermometer to fall 1°.5 C. within a few seconds when a sudden breeze sprang up, succeeding a calm. These facts show that a comparison of humidity readings between different stations at any given instant of time is open to serious error, and even the readings of the dry-bulb thermometer may vary locally owing to local conditions.

In the following discussion I shall consider a "formation" as a group of plants of definite composition as to species, occupying a definite habitat as to the physical characteristics of the latter, or a definite area as to geographical position. A "society" is a definite group of plants as to component species occupying a secondary position within a formation. The "characteristic species" of a formation are those which dominate the area occupied by that formation. Thus the "characteristic species" of the "cottonwood-willow formation" of the lower cañons and plains are *Populus occidentalis* and *Salix fluviatilis*. Within this "formation" we find the Crataegus and Corylus "societies."[7]

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[5] All temperatures are recorded in degrees Centigrade.

[6] The great difference between the maximum at Boulder and three miles east of Boulder is doubtless traceable to the different elevations of the instruments above the ground at these points.

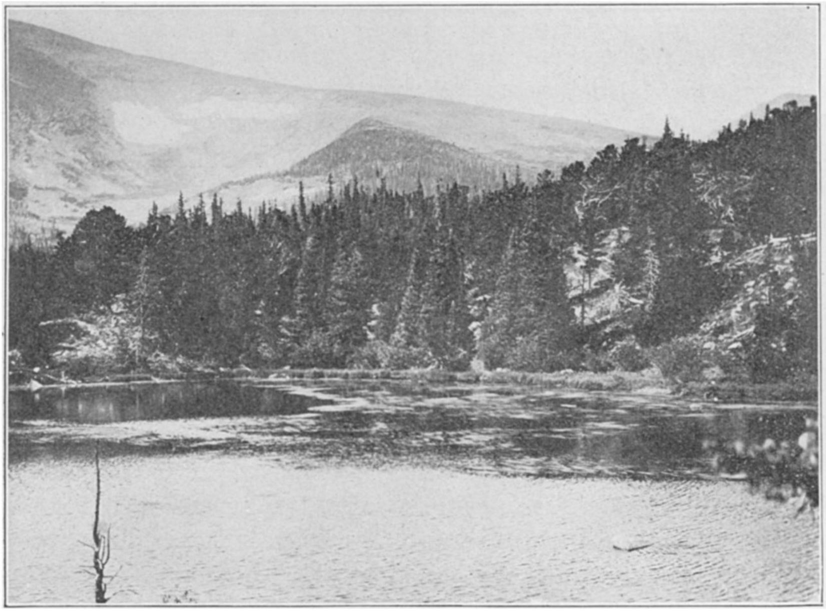

FIG. 4.—The Picea-Abies formation with a glacial pond in middle foreground.

## Composition of the forests

The forests of Boulder County may be classed under the following formations: (1) Populus occidentalis–Salix fluviatilis formation; (2) Populus angustifolia–Salix Nuttallii formation; (3) Pinus scopulorum formation; (4) Pinus Murrayana formation; (5) Apinus flexilis formation; (6) Pseudotsuga–Picea Engelmanni formation; (7) Picea Engelmanni–Abies lasiocarpa formation.

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[7] I have given these definitions for the sake of clearness, but with no claim of originality. The nomenclature of the paper is that used by RYDBERG (*op. cit.*).

While *Populus tremuloides* occupies numerous areas through the mountains, I have not thought best to consider it of higher rank than a society. My reason for denying it formational rank is that it occupies varying habitats, associating with the other formations, and never dominating areas which are well defined either as to their physical features or geographical position.

All these formations are montane excepting the first, and even this extends up the cañons to about 1950$^m$. The second, on the contrary, while chiefly montane, overlaps the first on the plains.

### (1) THE POPULUS OCCIDENTALIS–SALIX FLUVIATILIS FORMATION (*fig. 12*)

This formation occupies the banks of streams on the plains and, as already mentioned, is found also in the lower cañons. It is a straggling tree formation scarcely worthy the name of forest. While restricted mainly to the stream banks, groves of trees may occasionally be found along the borders of the old flood plains.

It is a very mixed formation, consisting essentially of two layers, an upper woody layer and a lower herbaceous one. The former may be divided into two subordinate layers, one controlled by *Populus occidentalis* and the other by *Salix fluviatilis*. These are not, however, usually coexistent, but alternate, the cottonwood controlling here and the willows there. Associated with the two characteristic species of the formation are many individuals of *Populus angustifolia*, but these do not control. A few scattered shrubs occur in the formation but are not sufficiently numerous to be considered as an independent layer (see below). The herbaceous layer, moreover, might be separated into two subordinate ones; but since its constituent forms present every gradation in height, such a separation would be entirely arbitrary and superficial. A ground layer of mosses and liverworts is occasionally present.

The formation is an open one. Occasionally the trees form a sufficiently dense growth to exclude all but the more shade-loving species, but for the most part they are separated by intervals of many feet, thus permitting the entrance of a large amount of sunlight and admitting most of the species from the adjoining formations. These species are largely ruderal, owing to the presence of cattle and the proximity of farms and highways.

Of the weeds entering into the formation some of the commonest are *Medicago sativa*, *Melilotus alba*, *M. officinalis*, *Trifolium pratense*, *T. repens*, *Phleum pratense*, *Poa pratense*, *Bromus brizaeformis*, *Polygonum lapathifolium*, *Verbascum thapsus*, *Ambrosia trifida*, *Solidago canadensis*, and *Helianthus grosseserratus* (?).

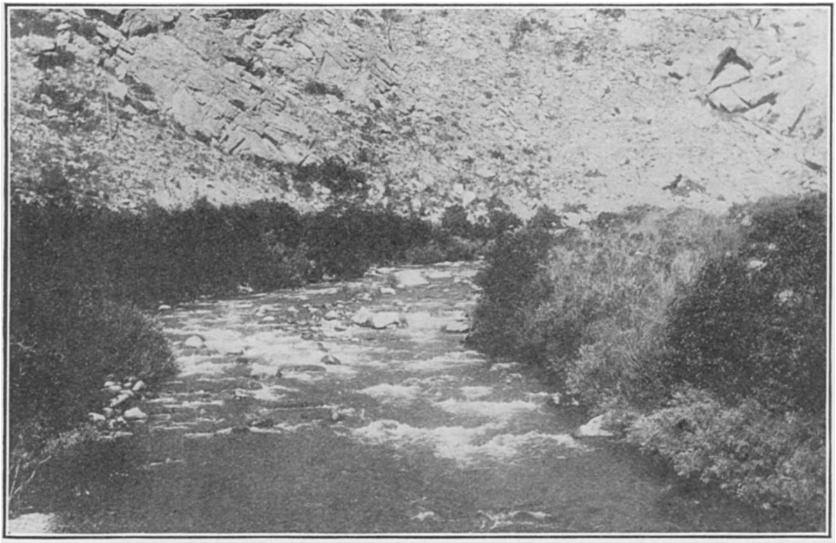

FIG. 5.—The Populus occidentalis–Salix fluviatilis formation, two miles above the mouth of Boulder Cañon; to the left the control is shared by *Populus occidentalis* and *Rulac negundo;* to the right *Salix fluviatilis* dominates.

In the more dense parts of the formation, the forms of the under layer are more sparse both as to number of species and number of individuals. Three of the more characteristic are *Anemone canadensis*, *Vagnera stellata*, and *Viola canadensis*.

The stream banks form a path along which some of the montane species are invading the plains. Hence we find in the cottonwood formation a few such forms as *Viola canadensis* and *Apocynum* *androsaemifolium.* A few species from the adjoining plains are invading the formation. These include an occasional *Artemisia* sp. and a few individuals of *Festuca octoflora. Eleocharis palustris* wanders in occasionally from nearby meadows.

While the under layer of the formation is so mixed that it is difficult to assign a dominant rôle to any forms, yet in general it may be said that this layer is characterized by *Agrostis alba* and *Melilotus alba.* The vernal aspect is not derived from any species or group of species, the color of the vegetation at this season being mainly green. In its late aestival and autumnal aspect the yellow of Solidago and Helianthus gives to the vegetation its predominant color.

In the lower cañons (*fig. 5*) the formation maintains the loose straggling character which it presents on the plains. Here, however, an intermediate layer of shrubs forms one of the most important parts of the formation (*figs. 5, 6*). Chief among these are *Alnus tenuifolia* and *Corylus rostrata.* Other members of this layer are *Crataegus cerronis, C. coloradoensis, Clematis ligusticifolia, Ampelopsis pentafolia, Prunus americana, P. melanocarpa, Rosa pratincola,* and *Acer glabrum.* In the densely shaded thickets formed by these shrubs, the under layer is composed mainly of *Hydrophyllum Fendleri, Viola canadensis, Galium trifidum,* and *Vagnera stellata.* Species from the higher slopes occasionally wander in, such as *Berberis Fendleri* and *Prunus melanocarpa.*

In places where the light value falls as low as 5 : 300, the under layer is largely lacking.

Mixed as is this formation on the plains, in the narrow and steep-sloped cañons its continuity is still more difficult to follow. The species from the adjoining shrub-grass formation of the cañon sides come down to the bottom of the cañon and mingle with those of the cottonwood-willow formation, ruderals are numerous, and along the stream banks members of the brookside formation, such as *Collinsia parviflora, Mimulus minor,* and *Veronica peregrina,* are found. Wherever sandbars are formed by the shifting current of the streams on the plains, the cottonwoods, principally *Populus occidentalis,* are invading them in large numbers. Such invasions, for the most part, are only temporary, however, on account of the floods which in spring overflow these sandbars, destroying the plants on them.

Owing to the physical condition of the surrounding habitats, the Populus occidentalis–Salix fluviatilis formation is in a practically static condition. My data on the physical characters of the habitat of this formation are as follows:

Observations taken on Boulder Creek east of Boulder during July 1905 gave results as follows:

*Temperatures**

(Observations July 3, 11 A. M.; 10, 10:45 A. M.; 24, 11:15 A. M.; 28, 1:45 P. M.)

| | $-22.5^{cm}$ | $-11.25^{cm}$ | $0^{cm}$ | $+7.5^{cm}$ | $+9^{dm}$ |
|---|---|---|---|---|---|
| Minima...... | 16°.2 | 16° | 16°.6 | 20°.5 | 21°.2 |
| Maxima...... | 20°.25 | 18°.5 | 31°.25 | 26°.5 | 25°.5 |

* Zero indicates the ground surface, minus readings below surface, and plus readings above the surface.

*Water content*

| Observations | $11.25^{cm}$ | $22.5-11.25^{cm}$ |
|---|---|---|
| July 10...... | 30.1 per cent. | 18.3 per cent. |
| July 24...... | 8.8 per cent. | 9 per cent. |

*Relative humidity*

(Observations July 3, 11 A. M.; 10, 10:45 A. M.; 24, 11:15 A. M.; 28, 1:45 P. M.)

| | $7.5^{cm}$ | $9^{dm}$ |
|---|---|---|
| Minima...... | 43 per cent. | 38 per cent. |
| Maxima...... | 73 per cent. | 60 per cent. |

The light value in this formation taken above the under layer at noon on August 7 was 9 : 180.

In a thicket of *Corylus rostrata* at the mouth of Boulder Cañon, three series of observations gave the following results:

*Temperatures*

(Observations June 24, 10:15 A. M.; July 17, 12:20 P. M.; August 30, 7 A. M.)

| | $-22.5^{cm}$ | $-11.25^{cm}$ | $0^{cm}$ | $+7.5^{cm}$ | $+8^{dm}$ | $+1.8^{m}$ |
|---|---|---|---|---|---|---|
| Minima...... | 13°.5 | 13°.8 | 14°.4 | 16°.75 | 17° | 17°.5 |
| Maxima...... | 18° | 18° | 21°.5 | 25°.5 | 27° | 27°.5 |

*Water content*

| Observations | $11.75^{cm}$ | $22.5-11.25^{cm}$ |
|---|---|---|
| June 24...... | 29.5 per cent. | 24.6 per cent. |
| July 17...... | 12.5 per cent. | 12.4 per cent. |
| Aug. 30...... | 5.3 per cent. | 7.2 per cent. |

*Relative humidity*

(Observations June 24, 10:15 A. M.; July 17, 12:20 P. M.; August 30, 7 A. M.)

| | $7.5^{cm}$ | $9^{dm}$ | $1.8^{m}$ |
|---|---|---|---|
| Minima........ | 30 per cent. | 27 per cent. | 26 per cent. |
| Maxima........ | 80 per cent. | 83 per cent. | 88 per cent. |

In a hawthorn society at the mouth of a small cañon at an altitude of $1710^{m}$, observations were made at three stations. One of these was in the center of the thicket, close to a small stream; this I shall designate as Station E. A second station, which I have called $E_1$, was chosen about midway between the center and edge of the thicket; and the third, or Station $E_2$, was taken just at the edge of the thicket. The results obtained for these three stations follow:

*Temperatures*

Station E (Observations June 12, 7 P.M.; 13, 6 P.M.; July 1, 8:15 A.M.; 8, 10:30 A.M.; 17, 9:10 A.M.; August 26, 9:45 A.M.)

| | $-22.5^{cm}$ | $-11.25^{cm}$ | $0^{cm}$ | $+7.5^{cm}$ | $+9^{dm}$ | $+1.8^{m}$ |
|---|---|---|---|---|---|---|
| Minima...... | 14°2 | 13° | 14° | 12°* | 12° † | 16° † |
| Maxima...... | 19° | 20°75 | 25° | 26°5* | 26°5 † | 28° † |

* Five observations.

† Four observations.

Station $E_1$ (Observations June 13, 6 P.M.; July 1, 8:45 A.M.; 8, 11 A.M.)

| | $-22.5^{cm}$ | $-11.25^{cm}$ | $0^{cm}$ |
|---|---|---|---|
| Minima................ | 13°6 | 13°4 | 13° |
| Maxima................ | 15°2 | 15°5 | 16°8 |

Station $E_2$ (Observations June 13, 7 P.M.; July 1, 9:15 A.M.; 8, 11:15 A.M.)

| | $-22.5^{cm}$ | $-11.25^{cm}$ | $0^{cm}$ |
|---|---|---|---|
| Minima................ | 14°75 | 15° | 14°6 |
| Maxima................ | 17°6 | 17° | 19°5 |

*Water content*

| | Observations | $11.25^{cm}$ | $22.5-11.25^{cm}$ |
|---|---|---|---|
| Station E....... | June 14 | 22.8 per cent. | 30.8 per cent. |
| | July 1 | 25.3 per cent. | 33.3 per cent. |
| | July 8 (raining) | 25.8 per cent. | 35.6 per cent. |
| | July 17 | 11 per cent. | 16.7 per cent. |
| | August 26 | 6.2 per cent. | 9.6 per cent. |
| Station $E_1$...... | July 1 | 14.4 per cent. | 15.4 per cent. |
| | July 8 (raining) | 18.6 per cent. | 13.3 per cent. |
| Station $E_2$...... | July 1 | 6.2 per cent. | 13.3 per cent. |
| | July 8 (raining) | 10.2 per cent. | 16.3 per cent. |

*Relative humidity*

Station E (Observations, June 12, 7 P.M.; 13, 6 P.M.; July 1, 8:15 A.M.; 8, 10:30 A.M.; 17, 9:10 A.M.; August 26, 9:45 A.M.)

| | $7.5^{cm}$ | $9^{dm}$ | $1.8^{m}$ |
|---|---|---|---|
| Minima........ | 45 per cent. | 42 per cent. | 21 per cent. |
| Maxima........ | 80 per cent. | 77 per cent. | 77 per cent. |

*Light value*

Station E............... August 26 9:45 A. M. = 5: 300

### (2) THE POPULUS ANGUSTIFOLIA–SALIX NUTTALLII FORMATION (*fig. 1*)

The transition between this and the preceding formation is a wholly gradual one, the narrow-leaf cottonwood occurring, as already noted, as a secondary form in the preceding formation. The upper limit of *Populus occidentalis* is about 1950$^{m}$. At this altitude it is replaced by *Populus angustifolia.*

Like the preceding, this formation lacks continuity, the characteristic species only occasionally exercising control, and being interrupted in places by the Pseudotsuga-Picea formation. In scattered association with *Populus angustifolia* and *Salix Nuttallii* are *Alnus tenuifolia*, *Betula fontinalis*, *Acer glabrum*, and in the lower parts of the mountains an occasional *Salix Fendleriana*. These shrubs form a straggling society along the cañon bottoms and may be occasionally found running up the mountain sides in favored localities. Two under layers, one of flowering plants, the other of mosses, liverworts, and lichens, are usually present; but these layers, as well as the upper, lack continuity and are very open. The herbaceous, or middle layer, is very mixed and holds no definite level, owing to the varying height of its constituent species. The frequent presence of a highway in the

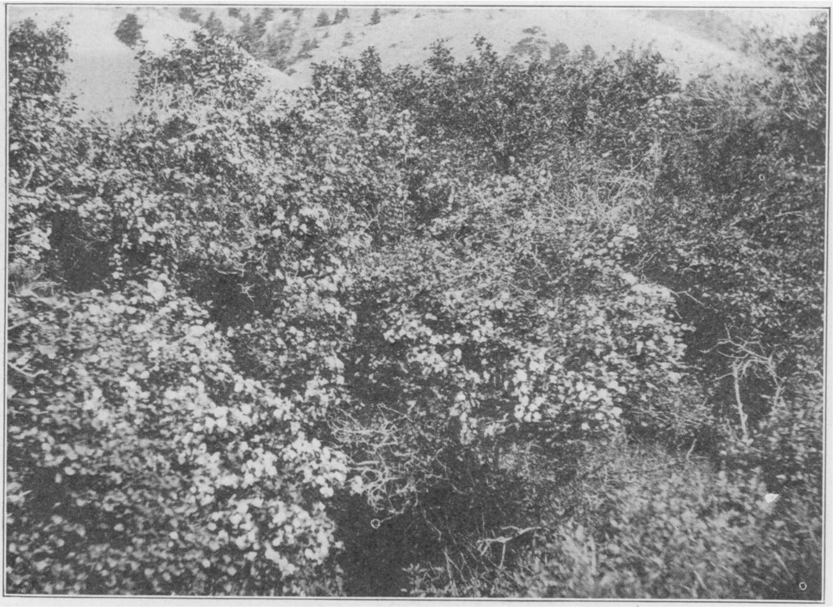

FIG. 6.—A hawthorn society.

cañon is causing the invasion of this formation by various weeds the commonest of which is *Trifolium repens*.

Common species of the middle layer are *Geranium Richardsoni*, *Rudbeckia ampla*, *Aconitum columbianum*, *Aquilegia coerulea*, *Viola canadensis*, *Heracleum lanatum*, and *Vagnera stellata*. Occasionally a *Mertensia ciliata* from the brookside formation of the Hudsonian zone wanders down the cañons to 2250$^{m}$.

In the upper limits of the formation the cottonwoods are mainly absent, the control here being shared by *Salix Nuttallii* and *Alnus tenuifolia*, with an occasional invasion of *Pseudotsuga mucronata*, *Picea Engelmanni*, *Picea Parryana*, and *Populus tremuloides*. In these places the ground is usually very wet and there are present in the middle layers, in addition to the forms already enumerated, *Senecio triangularis*, *Trollius albiflorus*, *Thalictrum occidentale*, *Oxypolis Fendleri*, *Panicularia nervata*, *Carex variabilis*, *Montia Chamissonis*, *Carex canescens*, *Agrostis hiemalis*, and *Geum oregonense*. The middle layer here is usually open, but occasionally the grasses or Carices form closed societies.

The formation is in a static condition. Within the cañons at least there is no apparent migration of the cottonwoods taking place, though an occasional *Salix Nuttallii* has invaded the mountain slopes to a point outside the proper limits of the formation.

The observations made in a thicket of *Corylus rostrata* and those in a hawthorn society, and recorded under the Populus occidentalis formation, apply equally well to this formation, since these formations overlap at this point, as I have already mentioned. In addition ot these observations, I have three observations taken during the summer of 1907. These observations were made at three stations which I shall call A, B, and C respectively. Stations A and B were in Boulder Cañon about 20$^{km}$ west of Boulder at an altitude of about 2250$^{m}$, while station C was at the mouth of Boulder Cañon. Station A was 6$^{m}$, B 6$^{dm}$, and C 1.2$^{m}$ from the edge of the stream.

My observations follow:

*Temperatures*

| | $-75^{dm}$ | $-15^{cm}$ | 0 | $9^{dm}$ |
|---|---|---|---|---|
| Station A. (June 26, 5 P.M.) | 11° | 13° | 14° | |
| Station C. (July 30, 5 P.M.) | | 16°5 | 19°2 | 21°2 |

| | | *Water content* | |
|---|---|---|---|
| | | $15^{\text{cm}}$ | $17–75^{\text{cm}}$ |
| Station A.* | (June 26) | 43.7 per cent. | 14.6 per cent. |
| Station B.* | (June 26) | 30.0 per cent. | ........ |
| Station C.† | (July 30) | 21.2 per cent. | ........ |

* Observations made following a period of showery weather.
† Rain two days previous.

### (3) THE PINUS-SCOPULORUM FORMATION (*fig. 2*)

This formation covers the dry slopes of the mountains from their base at an altitude of $1650^{\text{m}}$ to about $2400^{\text{m}}$. It is exceedingly open, the pines seldom exercising any decided control on the surrounding vegetation, except when associated with the Douglas firs. While the Pseudotsuga characteristic of the Pseudotsuga-Picea formation extensively overlaps the Pinus scopulorum formation, I have thought best to consider the two as distinct, because the characteristic habitat of each is distinctly different. Pseudotsuga, in the lower part of its range, is restricted to the north slopes and the cañon bottoms, while *Pinus scopulorum* occurs indifferently over north and south slopes alike, and is absent from the cool, moist cañon bottoms (see below). *Pinus scopulorum* is frequently associated in more or less dense clumps with Pseudotsuga, and where such is the case, or where the pines themselves grow densely, there is present no under layer whatever, with the exception of a few mosses and lichens. As soon as the formation becomes thinned out a little, shrubs and grasses from neighboring areas wander in. *Sabina scopulorum* is found in scattered association with the pines throughout the formation.

According to old residents of the county, the pines were formerly much more numerous than at present, having been largely cut for timber, this species having been formerly the principal timber tree of the mountains. At present comparatively little is being cut. The formation is in a dynamic condition. Large numbers of pine saplings are springing up throughout its extent, and on the mesas, which extend peninsula-like from the mountains on to the plains, are numerous strips of open pine forest, gradually invading the grass land of the plains.[8] An exposed sandstone cliff $11^{\text{km}}$ from the base of the mountains at Boulder bears in a crevice a young specimen of yellow pine.[9] Occasionally *Celtis reticulata*, a representative of the eastern forests, is found invading this formation.

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[8] RAMALEY (*op. cit.*, p. 31) explains the presence of trees on the west end of the mesas and their absence on the east end by a difference in moisture between the two. Since the pines grow on exposed south slopes of the mountains, however, where the water content is very low, this explanation does not appear to me fully satisfactory.

The absence of a secondary layer where the pines and Douglas firs grow densely is not to be explained alone on the ground of a scarcity of light or of moisture, but rather by the combined absence of these factors. The shade is seldom dense enough to exclude shade-loving plants, were sufficient moisture present to satisfy the needs of such forms.

The physical factors of this formation were taken at an altitude of about $2100^{m}$ on a north slope in a small grove of pines and Douglas firs. The results are given below:

*Temperatures*

(Observations July 29, 12:15 P. M.; August 14, 5:15 P. M.; September 13, 3:40 P. M.)

| | $-22.5^{cm}$ | $-11.25^{cm}$ | $0^{cm}$ | $+7.5^{cm}$ | $+9^{dm}$ |
|---|---|---|---|---|---|
| Minima...... | 16°.2* | 19°* | 18°.75 | 21°.75 | 22° |
| Maxima...... | 17.25* | 20°* | 26° | 27° | 26°.75 |

* Two observations.

*Relative humidity*

(Observations July 29, 12:15 P. M.; August 14, 5:15 P. M.; September 13, 3.40 P. M.)

| | $7.5^{cm}$ | $9^{dm}$ |
|---|---|---|
| Minima....... | 21 per cent. | 23 per cent. |
| Maxima...... | 65 per cent. | 35 per cent. |

*Water content*

| Observations | $11.25^{cm}$ | $22.5-11.25^{cm}$ |
|---|---|---|
| July 29........ | 3.7 per cent. | 4.4 per cent. |
| August 14...... | 3.6 per cent. | 2.6 per cent. |
| September 3.... | 1.6 per cent. | 2.1 per cent. |

*Light values*

September 13............. 3:40 P. M. = 4 : 60 (in medium shade)
= 4 : 360 (in direct shade of tree trunk)

### (4) THE PINUS MURRAYANA FORMATION (*figs. 7, 8*)

This formation replaces the Pinus scopulorum formation at about $2400^{m}$ altitude and stands between it on the one hand and the Apinus flexilis formation on the other, though it is overlapped by each of these, and indeed the two latter overlap each other at about this altitude. The question may be raised whether the *Pinus Murrayana* forests deserve recognition as an independent formation, or should be classed as a part of one or both of the two just named. Since, however, they occupy a definite zone, between 2400 and 3000$^m$, only occasionally straying up to 3300$^m$, which zone is not coincident with that of either of the two others, I have decided so to consider them.

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[9] In this connection see also SHANTZ, "A study of the vegetation of the mesa region east of Pike's Peak: the Bouteloua formation." BOT. GAZETTE 17:185, 186.

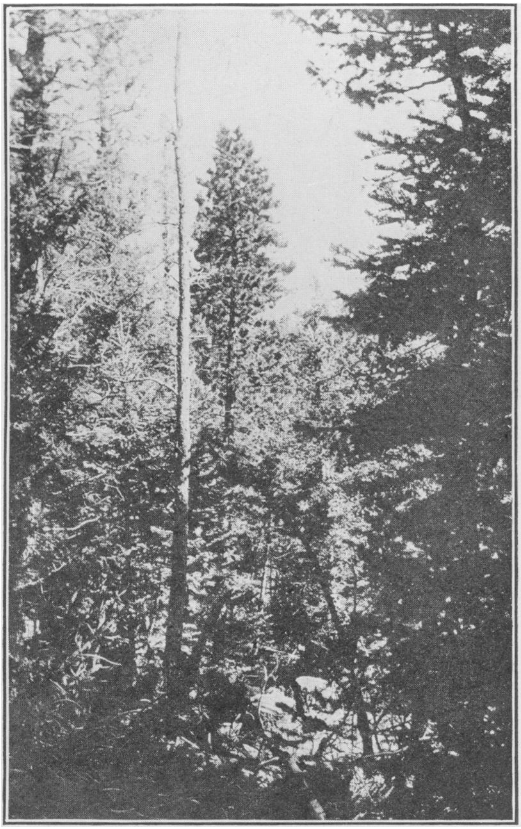

FIG. 7.—*Pinus Murrayana* and Pseudotsuga timber near Nederland, Colorado; approximate altitude 2550$^m$.

This formation occupies the dry mountain sides and is absent from the cañon bottoms. In the former situations it frequently mingles with the Pseudotsuga-Picea and Picea-Abies formations. Its habitat, however, is distinct from that of either of these. While this formation is much broken, alternating with the Carex-grass-shrub formation of the moraines and with the numerous societies of *Populus tremuloides*, it is less open than either of the other pine formations of the mountains. In some places the trees are separated by an average interval of but a few decimeters, which is usually the case in the younger groves. In the older forests there is ordinarily a greater interval between the trees. The normal abundance of the species in a forest formation in a region which has been burnt and timbered as extensively as have the mountains of Boulder County is obviously difficult to determine satisfactorily. But in comparison of apparently

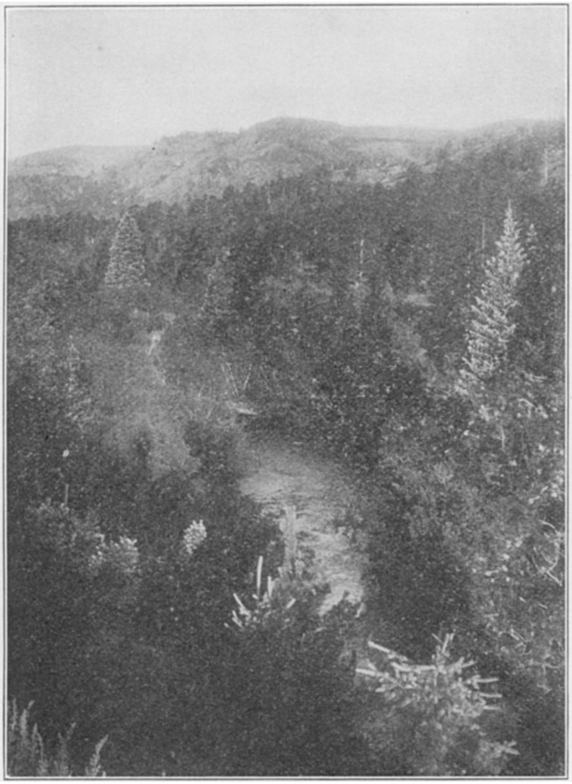

FIG. 8.—Boulder Creek between Nederland and Eldora, approximate altitude $2490^{m}$; in the cañon bottom *Alnus tenuifolia* and *Salix Nuttallii* dominate; the cañon sides are clothed with a mixture of the Apinus flexilis, Pinus Murrayana, Pseudotsuga-Picea, Picea-Abies, and Pinus scopulorum formation.

virgin tracts of *Apinus flexilis* and *Pinus Murrayana*, I find that the latter grows more densely than the former. I know of no virgin tracts of *Pinus scopulorum*.[10]

In the denser parts of the formation the under layer is very scanty, and consists mainly of *Pyrola secunda*, *Arctostaphylos uva-ursi*, and *Chimaphila umbellata*, with a few mosses and lichens. Where the formation is more open frequent invaders from the neighboring Carex-grass-shrub formation straggle in. *Razoumofskya americana* is a common parasite of *Pinus Murrayana*. Relative to the damage wrought by this and the preceding species of mistletoe see JACK (*op. cit.*, p. 45).

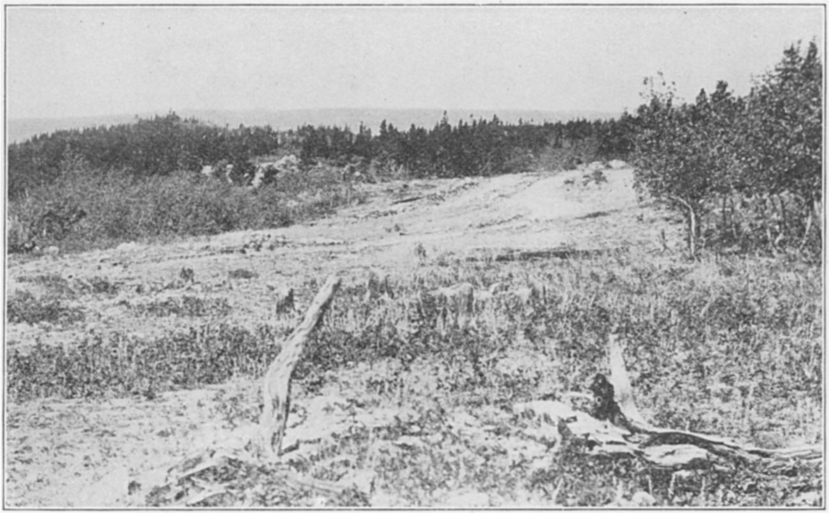

FIG. 9.—*Pinus Murrayana* and *Populus tremuloides* timber, two miles west of Sunset, Colorado; approximate altitude 2700$^{m}$.

The discussion of the deforestation and reforestation of the areas included in this and the succeeding formations I shall reserve for consideration under "Succession."

Observations of the physical character of the habitat of this formation were taken at two stations. One of these was in a mixed forest of *Pinus Murrayana* and *Pseudotsuga mucronata* at an approximate altitude of $2550^{m}$, with a northwest exposure. At this station three sets of observations were taken on July 13, 25, and August 29. The other station, at which but one set of observations was made on August 29, was in a grove of young pines on a northwest exposure at an approximate altitude of $2520^{m}$. The first of these I shall call Station A, the second Station B.

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[10] In this connection see also JACK, Pike's Peak, Plum Creek, and South Platte Reserves, U. S. Geol. Survey, 20th Ann. Rep., pt. 5, p. 50.

*Temperatures*

Station A (Observations July 13, 10:50 A. M.; 25, 3:20 P. M.; August 29, 6:45 A. M.)
Station B (Observation August 29, 1:40 P. M.)

|  | $-22.5^{cm}$ | $-11.25^{cm}$ | $0^{cm}$ | $+7.5^{cm}$ | $+9^{dm}$ |
|---|---|---|---|---|---|
| Minima...... | 9°.6 | 11° | 12°.5 | 14°.5 | 15°* |
| Maxima...... | 13° | 14°.5 | 26° | 23°.25 | 20°.25 |

* Two observations.

*Relative humidity*

Station A (Observations July 25, 3:20 P. M.; August 29, 6:45 P. M.)
Station B (Observation August 29, 1:40 P. M.)

|  | $7.5^{cm}$ | $9^{dm}$ |
|---|---|---|
| Minima....... | 43 per cent. | 45 per cent. |
| Maxima....... | 67 per cent. | 64 per cent. |

*Water content*

|  | Observations | $11.25^{cm}$ | $22.5-11.25^{cm}$ |
|---|---|---|---|
| Station A.......... | July 25 | 9.8 per cent. | 6.9 per cent. |
|  | August 29 | 6.7 per cent. | 9.5 per cent. |
| Station B.......... | August 29 | 5.3 per cent. | 4.2 per cent. |

### (5) THE APINUS FLEXILIS FORMATION

This formation occurs over the dry mountain slopes from $2550^{m}$ up to timber-line. In the lower part of its range it is represented by only a few scattering individuals, but above $3000^{m}$ it is the dominant pine formation. Here it extensively overlaps the Picea-Abies formation, but I have thought best not to classify it with the latter as Apinus-Picea-Abies formation, because it occupies as a rule higher, drier ground than the firs and spruces, which are found in the cañon bottoms as well as on the higher slopes.

Even in the virgin forest, the trees are separated by comparatively wide intervals, but their spreading tops meeting overhead produce a sufficiently dense shade to exclude all but a few straggling invaders from the open slopes, with the exception of the mosses and lichens and *Vaccinium microphyllum*, which form the characteristic layer of the forest floor. This last species forms a loose straggling layer in both this and the spruce-fir formation of the high mountains, attaining a height of only a few inches. Biologically, the under layer of this formation is open, but the physical conditions of its habitat are such as to exclude most plants.

Save where artificial conditions such as fire or lumbering have intervened, the continuity of this formation is comparatively unbroken, except in its lower limits, where it is represented only by a few straggling individuals.

Observations of the physical character of the habitat of this formation were made at two stations which I designate as A and B. Station A was on a gentle slope with a southwest exposure, at an approximate altitude of 2940$^{m}$. Station B was on a comparatively level area at an altitude of approximately 3150$^{m}$. A series of three observations at these stations gave the following results:

*Temperatures*

Station A (Observations July 5, 1:45 P. M.; 27, 11:15 A. M.; September 5, 12 M.)
Station B (Observation July 19, 6:30 A. M.)

| | $-22.5^{cm}$ | $-11.25^{cm}$ | $0^{cm}$ | $+7.5^{cm}$ | $+0.9^{m}$ |
|---|---|---|---|---|---|
| Minima...... | 5°.8 * | 6°.2 | 6° | 11° ‡ | 11° ‡ |
| Maxima...... | 8° † | 8° | 13°.4 | 14.5 ‡ | 13°.75 ‡ |

* Depth of 17.5$^{cm}$. † Depth of 20$^{cm}$. ‡ Three observations.

*Relative humidity*

Station A (Observations July 5, 11:45 P. M.; 27, 11:15 A. M.; September 5, 12 M.)
Station B (Observation July 19, 6:30 A. M.)

| | $7.5^{cm}$ | $9^{dm}$ |
|---|---|---|
| Minima........... | 34 per cent. | 27 per cent. |
| Maxima .......... | 63 per cent. | 59 per cent. |

*Water content*

| | Observations | $11.25^{cm}$ | $22.5-11.25^{cm}$ |
|---|---|---|---|
| Station A.......... | July 5 | 17.3 per cent. | |
| | July 27 | 18.5 per cent. | 8.7 per cent. |
| | September 5 | 21.4 per cent. | 5.5 per cent. |
| Station B.......... | July 19 | 16.1 per cent. | 11.7 per cent. |

The light value of the Apinus flexilis formation was taken at a point where this formation overlapped the Picea Engelmanni–Abies lasiocarpa formation, on September 8 at 11:30 A. M. The observation was made in the general shade of the forest, not in the direct shade of a tree trunk. The value was 5:180.

### (6) THE PSEUDOTSUGA MUCRONATA–PICEA ENGELMANNI FORMATION.

(*figs. 7, 8*)

This is the dominant formation of the cañons from 1800 to 2700$^{m}$. It mingles with the Pinus scopulorum and P. Murrayana formations on the ridges and with the Populus angustifolia formation in the cañon bottoms. *Pseudotsuga mucronata* is more common than the other characteristic of the formation and is far more extensive in its habitat than the latter. Besides *Picea Engelmanni*, *P. Parryana* occurs in the formation, forming a straggling society along the bottom of the cañons from $2100^{\mathrm{m}}$ to $2700^{\mathrm{m}}$. Both of these species are confined to the cool, moist cañon bottoms and the draws running into them. The Pseudotsugas, on the contrary, extend up on to the dry ridges to associate with the pines growing there. They come down the cañons to $1710^{\mathrm{m}}$, while the lowest limit of Picea is about $1950^{\mathrm{m}}$.

I have already mentioned the fact that Pseudotsuga, in the lower part of its range, is restricted to the north slopes.[11] A comparison of the physical conditions of the opposite slopes of Left Hand Cañon at an approximate altitude of $2100^{\mathrm{m}}$ was made by me on September 20, 1905. Two stations were selected, one on the south side (north slope) of the cañon and the other on the north side (south slope). The former slope was well covered with aspens, the station being chosen in a little glade among them. The latter slope was sparsely forested with aspens and pines (*P. scopulorum*). Each station was about $9^{\mathrm{m}}$ above the stream. The former I have designated as A and the latter as B. The following are my results, the observations being made September 20, 1905:

*Temperatures*

| | $-22.5^{\mathrm{cm}}$ | $-11.25^{\mathrm{cm}}$ | $0^{\mathrm{cm}}$ | $+7.5^{\mathrm{cm}}$ | $+0.9^{\mathrm{m}}$ |
|---|---|---|---|---|---|
| Station A, 2:15 P. M. | 7°.5 | 9°.5 | 10°.5 | 20°.25 | 21°.7 |
| Station B, 2:50 P. M. | 22°.5 | 19° | 43° | 28°.5 | 25°.5 |

*Relative humidity*

| | $7.5^{\mathrm{cm}}$ | $9^{\mathrm{dm}}$ |
|---|---|---|
| Station A, 2:15 P. M. | 32 per cent. | 27 per cent. |
| Station B, 2:50 P. M. | 25 per cent. | 26 per cent. |

*Water content* *

| | $1^{\mathrm{m}}$ depth | $22.5^{\mathrm{cm}}$ depth † |
|---|---|---|
| Station A | 4.9 per cent. | 11.3 per cent. |
| Station B | 2.7 per cent. | 3.3 per cent. |

* The preceding evening was showery and rain probably fell at these stations.

† A few centimeters core was taken at each depth.

As the result of lumbering and fires, this formation has been extensively invaded by forms from adjoining open slopes, but typically it is a closed formation admitting only a few shade plants. Where it overlaps the pine formations on the ridges, its secondary layer is the same as already described for them. In the cañon bottoms it is invading the Populus angustifolia–Salix Nuttallii formation, while it in turn is invaded by forms from the open cañon slopes. Where the tree growth is dense, however, it is practically exclusive of all forms except a few mosses and lichens and an occasional *Pyrola secunda* or *Arnica cordifolia.* The formation has been lumbered extensively, the Douglas fir being used to a considerable extent for rough bridge timbering and similar purposes.

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[11] In this connection see also JACK (*op. cit.*, p. 434, *pl. 12*); SHANTZ (*op. cit.*, pp. 34, 40); and RAMALEY (*op. cit.*, pp. 31 et seq.).

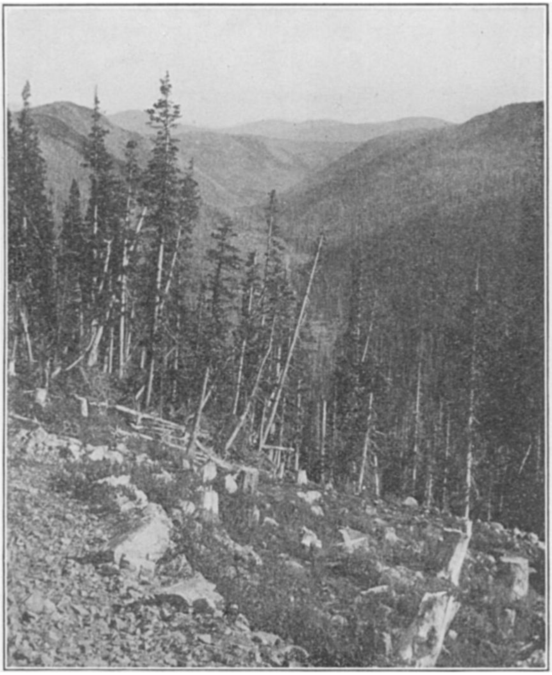

FIG. 10.—The Picea-Abies formation; approximate altitute 3300m; in the background is seen an extensive burned area.

For the physical characters of the habitat, reference may be made to the results recorded for the Pinus scopulorum formation, and for Station A in the Pinus Murrayana formation, since both of these sets of results are representative of the higher, drier parts of the Pseudotsuga habitat. One other set of observations was made at the bottom of Boulder Cañon at 3:40 P. M. on August 29 at an approximate altitude of $2250^{m}$. Here *Picea Engelmanni* is common and the physical factors typical of the cool, moist portions of the habitat of this formation. The results obtained at this latter point are as follows:

*Temperatures*

| $-22.5^{cm}$ | $-11.25^{cm}$ | $0^{cm}$ | $+7.5^{cm}$ | $+9^{dm}$ |
|---|---|---|---|---|
| 11°5 | 14° | 17° | —— | 18°7 |

*Water content*

| $11.25^{cm}$ | $22.5-11.25^{cm}$ |
|---|---|
| 135.7 per cent. | 5.8 per cent. |

### (7) THE PICEA ENGELMANNI–ABIES LASIOCARPA FORMATION

### (*figs. 4, 10, 11*)

This formation occupies chiefly the cañons and to a lesser extent the ridges of the mountains from $2850^{m}$ to timber-line, in the latter situation mingling with the Apinus formation. The two characteristic species are of comparatively equal abundance, although the firs are more numerous above $3000^{m}$ and do not extend much below $2400^{m}$; while the spruces are more abundant below $3000^{m}$ and pass down, as already noted, to $1950^{m}$.

Where the forest is virgin it forms a dense growth, excluding practically all forms except *Vaccinium microphyllum* and a few mosses and lichens. Along the wet stream banks through the forest, however, we find the brookside formation of the Hudsonian zone characterized by *Caltha leptosepala*, *Mertensia ciliata*, and *Senecio triangularis*, while occasional invaders from adjoining open slopes occur in the more open parts of the formation. Of these must be noted especially *Erigeron salsuginosus* and *Pedicularis racemosa*. It is doubtful whether the latter form is to be considered as an invader or not. It is more common in open timber than in clearings, but does not occur in the dense forest.

The results obtained from observations in the Apinus flexilis formation are representative of the drier part of the habitat of this formation. In addition to these results are those obtained at two other points within this formation. The first of these, which I shall designate as Station A, was near the head of a wooded cañon, and in its lower part, at an approximate altitude of $3150^{m}$. The slope was gentle, the exposure southeast. The second point, which I shall designate as Station B, was in this same cañon at an approximate altitude of $3300^{m}$, on a steep south slope.

*Temperatures*

| | Observations | $-22.5^{cm}$ | $-11.25^{cm}$ | $0^{cm}$ | $+7.5^{cm}$ | $+0.9^{m}$ |
|---|---|---|---|---|---|---|
| Station A* .. | June 20, 7 P. M. | —— | —— | 4°.6 | 8°.7 | 8°.7 |
| | June 21, 6 A. M. | —— | —— | 3°.2 | 2°.5 | 2°.2 |
| Station B.... | September 22, 4 P. M. | 7°.25 | 8°.25 | 14°.75 | —— | —— |

* The observations at this station were made while many snowdrifts still lay in the forest.

*Relative humidity*

| | Observations | $+7.5^{cm}$ | $+0.9^{m}$ |
|---|---|---|---|
| Station A............. | June 20, 7 P. M. | 40 per cent. | 40 per cent. |
| | June 21, 6 A. M. | 100 per cent. | 96 per cent. |

*Water content*

| | Observations | $11.25^{cm}$ | $22.5-11.25^{cm}$ |
|---|---|---|---|
| Station A........ | June 20, 7 P. M. | 227 per cent. | —— per cent. |
| Station B........ | September 22, 4 P. M. | 20.9 per cent. | 20.9 per cent. |

*Light value*

For light value, refer to Apinus formation.

### (8) THE ASPEN SOCIETY (*fig. 9*)

I have already stated my reasons for not considering the groves of aspens as a distinct formation. They have an individuality as a society, however, among the other forest formations which entitles them to separate consideration at this point.

This society occurs within the limits of the other formations. It usually occurs as a distinct society, but occasionally loses its individuality, mingling intimately with the trees of the other forests. It is distributed throughout the mountains from $1800^{m}$ to $3150^{m}$, being confined in the lower part of its range to the north slopes, but in the higher mountains being distributed indifferently over both north and south slopes. It may occur either as a scattered grove of trees, exercising but little if any control upon the lower layers of the vegetation; or it may form a forest with the trees growing within a few feet of each other, in which case it does exercise a decided control upon the lower layers.

The physical conditions in such a forest are intermediate between those in the dense spruce and fir timber of the cañon bottoms and the exposed mountain slopes. The height of the trees and density of the foliage is not such as to produce more than a moderate amount of shade, so that the under layer is not composed exclusively of dense shade-loving species, while the amount of moisture retained by the soil is sufficient to support an abundant growth of plants. The under layer is mixed and for the most part open. Some of the more frequent members are *Artemisia tridentata*, *Arctostaphylos uva-ursi*, *Achillea lanulosa*, *Poa triflora*, *Antennaria parvifolia*, *Poa pratensis*, *Aquilegia coerulea*, and *Castilleja acuminata*.

A series of three observations of the physical characters of the habitat of this formation, taken at a point at $2490^{\mathrm{m}}$ altitude approximately, in a little hollow where the general slope was southwest and very gradual, gave the following results,[12] the observations being made July 5, 6:10 P.M.; 25, 4:05 P.M.; August 28, 5:45 P.M.

*Temperatures*

| | $-22.5^{\mathrm{cm}}$ | $-11.25^{\mathrm{cm}}$ | $0^{\mathrm{cm}}$ | $7.5^{\mathrm{cm}}$ | $9^{\mathrm{dm}}$ |
|---|---|---|---|---|---|
| Minima | 14°5 * | 12° | 11°2 | 11° | 11°5 |
| Maxima | 14°5 * | 16° | 19° † | 17°5 | 18°25 |

*Relative humidity*

| | $7.5^{\mathrm{cm}}$ | $9^{\mathrm{dm}}$ |
|---|---|---|
| Minima | 68 per cent. | 55 per cent. |
| Maxima | 89 per cent. | 71 per cent. |

*Water content*

| Observations | $11.25^{\mathrm{cm}}$ | $22.5-11.25^{\mathrm{cm}}$ |
|---|---|---|
| July 5 | 17.3 per cent. | —— |
| July 25 | 21.1 per cent. | 7.9 per cent. |
| Aug. 28 | 20.9 per cent. | 9.1 per cent. |

*Light value*

August 27, 10 A. M. ........................ =5 : 90

* One observation only, August 28.

† Four observations, this recorded on July 14.

CLEMENTS,[13] recognizes the following forest formations in the Pike's Peak region of Colorado: Pinus edulis–Juniperus (monosperma); Pinus ponderosa–flexilis; Populus tremuloides; Picea Engelmanni and Parryana–Pseudotsuga (mucronata); Picea Engelmanni–Pinus (aristata). The first of these is not represented in Boulder County. My reasons for recognizing the Pinus scopulorum,

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[12] See also the results obtained at Station A on September 20.

[13] CLEMENTS, F. E., Formation and succession herbaria. Univ. Nebr. Studies 4:329–355.

Apinus flexilis, and Pseudotsuga formations as distinct, and for degrading the Populus tremuloides formation to the rank of a society, have been given in detail in the discussion of these formations. *Pinus aristata* is a southern form not occurring in this region so far as I know.

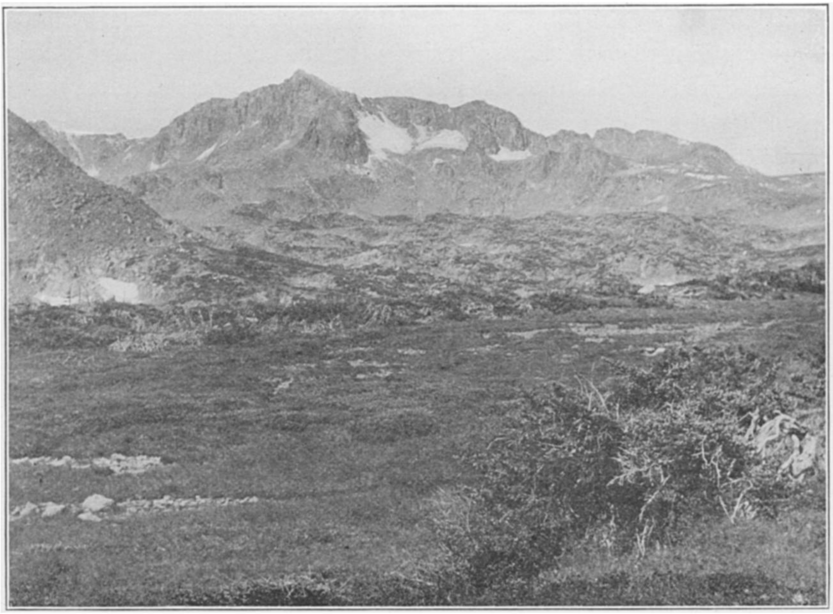

FIG. 11.—Timber-line on Mt. Arapahoe, south slope; approximate altitude $3450^m$; to the right is a small clump of spruce and fir.

## Invasion and succession

The soil of the mountain sides is the result of disintegration of the talus slopes with which they are covered. It is a loose gravel composed of particles of rotten granite, which is very readily eroded and forms an unstable foothold for plants. It is continually working its way downward into the cañons.

I have been unable to determine any sharply defined successional stages within any of the forest formations. The first invaders of a new or denuded soil are determined primarily by proximity, secondarily by mobility. On rough talus slopes, where there has been as yet but little disintegration, the principal forms present are the lichens, but even here occasional shrubs and grasses may be found growing in crevices where a little soil has collected. On loose gravel slopes denuded by erosion, herbs, shrubs, and even trees from neighboring formations, may pass in indiscriminately. Along railroad cuts and embankments and in new soils generally, which are close to highways or other paths of ruderal migration, those forms are among the first invaders, but they are not exclusively the first to enter. Associated with them are forms from the surrounding formations, and these may be either herbs or shrubs, while in some instances trees are the first invaders of a new soil. As an instance of the latter we have the invasion of sand flats on Boulder Creek by *Populus occidentalis.*

All of the forest formations of the higher mountains have been extensively denuded by fire (*figs. 3, 10*). The Pinus scopulorum formation has not recently been burned extensively, due doubtless to the fact that the pines form such a scattered growth that it is difficult for fires to spread to any extent among them. While the aspens play a large part in the reforestation of these burned areas, owing to the mobility of their seeds and the readiness with which they reproduce from roots left uninjured in the burned area, their share in reforestation is not exclusive. Thus any other of the forest trees may reforest a denuded area without the intervention of any aspen stage in the succession, while pines and aspens may reforest a denuded area simultaneously.

In the numerous meadows of glacial origin in the higher mountains, there is proceeding a gradual invasion of the meadows by the Picea-Abies forest adjoining them, the latter representing the final stage in a succession initiated by mosses, sedges, and grasses; these in turn to be replaced by beeches and willows, and these latter finally to make way for the forest. These stages, however, are not sharply defined. The forest may succeed the sedges and grasses directly, without the intervention of willows and beeches, or the latter may succeed the grasses and sedges simultaneously with the forest.

The life-zones of the mountains in Boulder County may be outlined as follows, based upon the forests of the region: *Alpine zone,* characterized by absence of trees, above 3300 to 3450$^{m}$; *Hudsonian zone,* characterized by *Apinus flexilis* and *Abies lasiocarpa,* 2850 to 3450$^{m}$;

*Canadian zone*, characterized by *Pinus Murrayana*, 2400 to 2850$^{m}$; *Transition zone*, characterized by *Pinus scopulorum*, 1650 to 2400$^{m}$.

While physical factors are so closely interrelated that it is very difficult to separate them in determining what factors exercise the greatest influence in limiting the formations, we may at least limit these factors to two in answering the question "Why are zones present in mountain forests?" The factors of light and humidity may be rejected at once, since their variation at different altitudes is practically negligible. The obvious answer is that mountain zonation is due entirely to temperature. We have already seen that the difference in temperature between timber-line and the base of the mountain is very marked and the same is true, even to a greater extent, of the length of the growing-season. That water content may play as great if not a greater rôle than temperature, however, is at least possible. I have already noted the fact that the rainfall in the high mountains is about 25$^{cm}$ more annually than on the lower slopes.

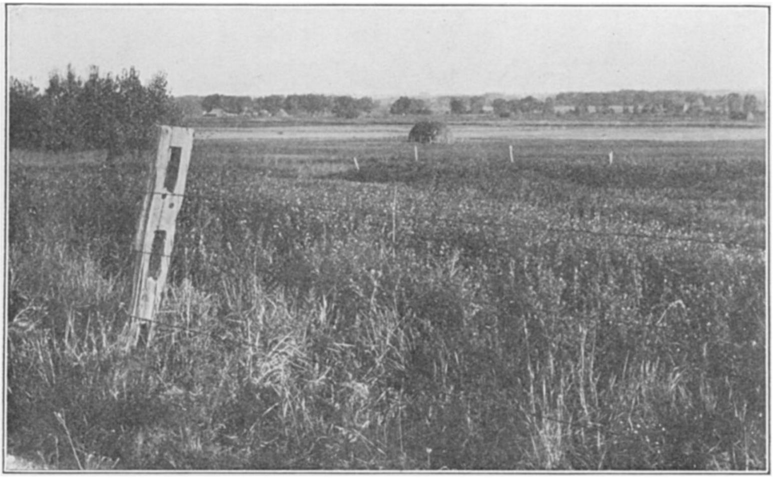

FIG. 12.—The Populus occidentalis formation in the valley of Boulder Creek, six miles east of Boulder; approximate altitude 1590$^{m}$.

The part played, moreover, by the development of the formations and their relation to the glacial history of the country may be very considerable. At present I have not sufficient data to enable me to discuss this question fully.

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UNIVERSITY OF NORTH DAKOTA